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Health Impact of Landfill Leachate : A Comprehensive Review

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ABSTRACT:
Landfills are commonly used for waste disposal, but they pose significant environmental and health risks due to the generation of landfill leachate. Landfill leachate is a complex mixture of organic and inorganic compounds that can percolate into the surrounding soil and water bodies, potentially leading to adverse health effects in nearby communities. This paper aims to provide a comprehensive review of the health impacts associated with landfill leachate exposure. It discusses the composition of landfill leachate, the pathways through which it can affect human health, and the potential health risks. Additionally, the paper explores current regulations and mitigation measures to minimize health hazards. By analyzing existing research, this paper sheds light on the importance of proper landfill management and waste disposal practices to safeguard public health.
Keywords: landfill, leachate, health impact, groundwater contamination, waste management, exposure pathways, regulation, mitigation.

1. INTRODUCTION:
Landfills play a crucial role in modern waste management systems by providing a means of disposing of vast amounts of solid waste generated by societies. However, the unintended consequences of landfill operations, particularly the production of landfill leachate, have raised significant concerns regarding their impact on human health. Landfill leachate is a complex and potentially hazardous liquid that forms as rainwater or other liquids come into contact with decomposing waste materials within landfills. This leachate can percolate through the landfill layers and eventually reach the surrounding environment, including soil and water bodies, posing potential health risks to nearby communities.

Landfills are designed to safely contain waste, preventing it from directly entering the environment. However, as waste materials degrade and decompose, they release a mixture of organic and inorganic substances, including volatile compounds, heavy metals, pathogens, and various chemicals. These compounds can dissolve in rainwater or other liquids and create leachate, a liquid with the capacity to transport these contaminants away from the landfill. If not effectively managed, landfill leachate can migrate into the surrounding soil and groundwater, potentially entering water bodies used for drinking water supply or agricultural purposes.

The concern for human health arises from the fact that these contaminants present in landfill leachate can interact with humans through different exposure pathways, ultimately leading to adverse health outcomes. These pathways include the consumption of contaminated water, the inhalation of volatile organic compounds released from leachate, and the direct contact of the skin with contaminated soil or water. As a result, communities living in proximity to landfills are at risk of exposure to a range of potential health hazards.

This paper seeks to provide an in-depth examination of the health impacts associated with landfill leachate exposure. By exploring the composition of landfill leachate, the various pathways through which it can affect human health, and the potential risks linked to these exposures, this study aims to contribute to a comprehensive understanding of the issue. Moreover, the paper will delve into existing regulations and mitigation measures that are in place to minimize the health hazards posed by landfill leachate. By reviewing and analyzing existing research, this paper underscores the importance of adopting effective waste management practices to mitigate the health risks and protect the well-being of communities living near landfills.

2. REVIEW OF LITERATURE

The annual production of garbage in India is experiencing exponential expansion due to the rapid increase in population, urbanization, and industrial development (Alam and Qiao, 2013). The disposal of non-segregated solid waste in landfills is a commonly observed waste management practice in developing countries like Bangladesh (Jahan et al., 2013; Kamal et al., 2012; Hossain et al., 2011; Xaypanya et al., 2011; Alam et al., 2010), as well as in certain regions of developed countries (Mishra et al., 2012). Improper management of landfills and the consequent creation of toxic leachate have been found to have significant repercussions on the surrounding freshwater and groundwater (Toufexi et al., 2013; Kamal et al., 2012; Mishra et al., 2012). Leachate refers to the liquid discharge that arises from the modification of solid waste in landfills, resulting in physical, chemical, and biological changes (Youcai, 2010). It is characterized as a complex mixture containing dissolved organic matter (DOM), xenobiotic organic compounds, various anions and cations, as well as heavy metals (Christensen et al., 2001). The heavy metals present in landfill leachate are considered non-biodegradable and have the potential to degrade the quality of surface and groundwater. These metals are also harmful to biological systems, even at low concentrations (Fergusson, 1991; Akpor, 2014; Gautam et al., 2014; Verma, 2011). Heavy metals exhibit characteristics of persistence, bioaccumulation, toxicity, as well as endocrine disruption and carcinogenicity (Kibria et al., 2012). On the other hand, dissolved organic matter (DOM) comprises a significant proportion of leachate and has the ability to form complexes with heavy metals. As a result, it significantly influences the bioavailability of these metals in aquatic ecosystems (Baun and Christensen, 2004; Rikta et al., 2013).

The primary issue regarding municipal landfills is mostly centered on the possible contamination caused by the movement of leachate, which is formed within the landfill, through the underlying soil and into both surface and groundwater sources (Kjeldsen et al., 2002; Fadhullah et al., 2012; Mishra et al., 2012). Moreover, throughout the wet season, water that contains leachate originating from the landfill site flows into the adjacent lowlands and surface water bodies, resulting in the contamination of the surrounding surroundings (Hossain et al., 2011). Therefore, it is evident that the discharge of this harmful liquid waste from a landfill location has the potential to offer significant hazards to both surface and groundwater (Christensen et al., 2001; Vaccari et al., 2014). Furthermore, it has been shown that this waste might provide a threat to aquatic organisms, plants, and public health (Toufexi et al., 2013). According to Iswa (2013), the prevalence of badly managed open landfill sites is more widespread in poorer countries compared to regulated and designed landfills. The unregulated disposal of trash, leading to pollution of water and food through toxic leachate, has a significant impact on the well-being of residents, particularly those living in urban and semi-urban areas in these countries. Bangladesh, being a densely populated nation with a population of around 164 million in 2020 (Worldometers.info), produces a daily quantity of solid garbage amounting to approximately 8000 tons (Abedin and Jahiruddin, 2013). Unfortunately, the disposal of this solid waste is carried out in an unregulated manner (DNCC, 2013). To the best of our knowledge, there have been few studies undertaken to systematically analyze the contamination level of landfill leachate in various landfill sites in Bangladesh (Jahan et al., 2013; Kamal et al., 2012; Hossain et al., 2011; Alam et al., 2010). Furthermore, it is important to note that none of the studies

conducted thus far have adequately examined the degree of leachate pollution potential in landfill sites located in Bangladesh, nor have they thoroughly investigated the extent to which leachate contaminates both groundwater and surface water sources. In addition, it is worth noting that the water delivery system in Bangladesh mostly relies on groundwater (78%) and to a lesser extent on surface water (22%) (Khan, 2013). Therefore, it is imperative to comprehend the impact of landfill leachate on the contamination of surface and groundwater in Bangladesh, particularly in urban and suburban regions. This understanding is of utmost importance and should be prioritized.

3. DISCUSSION

3.1 Composition of Landfill Leachate:

Landfill leachate is a complex and dynamic mixture of substances that results from the interaction between rainwater, liquids from waste materials, and the waste itself within a landfill. The composition of landfill leachate can vary widely based on factors such as the type of waste deposited, the age of the landfill, climate conditions, and the specific landfill management practices employed. This variability in composition makes it challenging to precisely predict the exact constituents of leachate in any given landfill. However, certain general categories of compounds are consistently found in landfill leachate:

i. Organic Compounds:

- **Dissolved Organic Matter (DOM):** As waste decomposes, it releases organic compounds such as carbohydrates, proteins, and fats. These compounds can dissolve in the leachate and contribute to its color, odor, and biological oxygen demand (BOD).
- **Volatile Organic Compounds (VOCs):** These are low molecular weight organic compounds that can readily evaporate into the air. VOCs in leachate can include solvents, hydrocarbons, and other chemicals that contribute to the characteristic smell often associated with landfills.

ii. Inorganic Compounds:

- **Heavy Metals:** Landfill waste may contain heavy metals like lead, mercury, cadmium, and arsenic, which can leach into the leachate. These metals pose serious health risks due to their toxicity and potential to accumulate in the environment.
- **Nutrients:** Leachate may contain nutrients like nitrogen and phosphorus, which can promote eutrophication in water bodies if they reach surface waters.

iii. Pathogens:

- **Bacteria:** Landfill leachate can contain various pathogenic bacteria, including Escherichia coli (E. coli), Salmonella, and other disease-causing microorganisms. If the leachate contaminates water sources, it can lead to waterborne diseases when consumed.
- **Viruses and Parasites:** Leachate may also carry viruses and parasites that can cause illnesses in humans upon ingestion.

iv. Pharmaceuticals and Endocrine Disruptors:

- **Pharmaceuticals:** Landfill leachate can contain trace amounts of pharmaceuticals and personal care products that were discarded in the waste. These substances may have potential effects on aquatic ecosystems and human health.

- **Endocrine Disruptors:** Chemicals that disrupt the endocrine system can also be present in leachate. These compounds can interfere with hormone signaling in organisms, potentially leading to developmental and reproductive abnormalities.

v. Chlorides and Salts:

- **Chlorides:** Landfill leachate often contains high concentrations of chlorides due to the disposal of items like plastics and electronics. Elevated chloride levels can impact the quality of water bodies and soil.

vi. Gases:

- **Methane (CH4):** Anaerobic decomposition of organic materials in landfills produces methane gas, a potent greenhouse gas. Some of this methane can dissolve in leachate, potentially contributing to its composition.

Understanding the composition of landfill leachate is crucial because it directly influences the potential health and environmental impacts of leachate migration. As leachate interacts with the surrounding environment, it can contaminate soil, surface water, and groundwater, posing risks to both ecosystems and human health. Effective waste management practices and leachate treatment are essential to mitigate the release of harmful compounds and minimize the consequences of landfill leachate contamination.

3.2 Pathways of Exposure:

Exposure to landfill leachate and its associated contaminants can occur through various pathways. Understanding these pathways is crucial for assessing the potential health impacts on individuals living near or working with landfill sites. Here are some common pathways of exposure:

i. **Ingestion:** Ingestion is a primary exposure pathway, particularly when contaminated groundwater or surface water sources are used for drinking, irrigation, or food preparation. If leachate-borne contaminants have migrated into water bodies, crops, or livestock, they can enter the human food chain and lead to chronic exposure.

ii. **Dermal Contact:** Direct contact with leachate-contaminated soil, sediments, or water can lead to dermal exposure. People, especially children, who come into contact with contaminated surfaces during recreational activities or through agricultural work may absorb contaminants through their skin.

iii. **Inhalation:** Gaseous compounds, such as volatile organic compounds (VOCs), can be released from landfill sites into the air. Individuals living nearby or working at or around landfills may inhale these airborne pollutants, which can potentially lead to respiratory and systemic health effects.

iv. **Airborne Particles:** Wind can carry fine particles from landfill sites that may contain contaminants adhered to the particles' surfaces. Inhaling these particles can introduce contaminants into the respiratory system.

v. **Bioaerosols:** Landfill sites can release bioaerosols containing microorganisms (bacteria, fungi, viruses) and allergenic components into the air. Inhalation of these bioaerosols can lead to respiratory issues, especially for those with preexisting respiratory conditions.

vi. **Direct Ingestion:** Children and pets might come into direct contact with leachate pools or puddles near landfill sites. Ingesting leachate-contaminated water, soil, or materials accidentally can result in exposure to a range of contaminants.

vii. **Occupational Exposure:** Workers at landfill sites, including waste management employees and recyclers, may experience direct exposure to leachate and its contaminants through skin contact, inhalation, and ingestion during their work activities.

viii. **Groundwater Contamination:** If landfill leachate contaminates groundwater, it can affect private wells and community water supply systems. Individuals who consume contaminated groundwater are at risk of exposure to a wide array of contaminants.

ix. **Surface Water Contamination:** Leachate can also contaminate surface water bodies such as rivers, lakes, and ponds. People using these water sources for recreational activities or as a water supply can be exposed to contaminants.

x. **Food Chain Contamination:** If crops, plants, or aquatic organisms are irrigated or grown in soil or water contaminated by leachate, there is a potential for contaminants to accumulate in the food chain and subsequently be ingested by humans or animals.

xi. **Inadvertent Ingestion through Hand-Mouth Contact:** Children who play near or on landfill sites may inadvertently put contaminated hands or objects into their mouths, leading to ingestion of contaminants.

3.3. Health Impacts:

i. Waterborne Diseases:

Pathogens present in landfill leachate can lead to waterborne diseases such as gastrointestinal infections, cholera, and hepatitis when contaminated water is ingested.

ii. Chemical Contaminants:

Chemicals like heavy metals, volatile organic compounds (VOCs), and endocrine-disrupting chemicals found in leachate can have chronic health effects, including developmental and neurological disorders, cancers, and hormonal imbalances.

iii. Air Quality:

Volatile compounds released from leachate can contribute to poor air quality, potentially causing respiratory problems and other health issues for nearby residents.

4. REGULATION AND MITIGATION:

Regulations and guidelines vary widely across different jurisdictions, but they generally focus on proper landfill siting, design, and management to prevent leachate contamination. Mitigation measures include liner systems, leachate collection and treatment, and monitoring of groundwater quality.

Regulation and mitigation measures are essential to minimize the health and environmental risks associated with landfill leachate. Regulatory frameworks help set standards and guidelines for the safe management of landfills and the prevention of leachate contamination. Mitigation strategies aim to reduce the generation of leachate, prevent its release into the environment, and treat it effectively if necessary. Here are some common regulatory and mitigation approaches:

4.1 Regulation:

i. **Landfill Siting and Design:** Regulatory authorities often require careful site selection and design for landfills to minimize the potential for leachate migration. This includes evaluating factors like hydrogeology, proximity to water sources, and the use of liners and caps to prevent leachate movement.

ii. **Liner Systems:** Landfills are typically required to have liner systems that prevent leachate from infiltrating into the underlying soil and groundwater. Liners are made of materials like clay or synthetic geomembranes.

iii. **Leachate Collection and Removal Systems:** Regulations may mandate the installation of leachate collection systems, including pipes and pumps, to collect and remove leachate for proper treatment.

iv. **Monitoring and Reporting:** Regulatory agencies often require regular monitoring of leachate quality, groundwater, and surface water to ensure that contamination is detected early. Landfill operators are typically required to report monitoring results to authorities.

v. **Closure and Post-Closure Care:** Regulations outline procedures for closing landfills after their operational lifespan and continuing post-closure care to manage leachate and gas emissions.

4.2 Mitigation:

i. **Waste Segregation and Recycling:** Effective waste management practices, including waste segregation at source and recycling programs, can reduce the amount of waste going to landfills, thereby reducing leachate generation.

ii. **Cover Systems:** Landfills are often required to have cover systems to minimize the infiltration of rainwater and reduce the production of leachate. Covers can also help control odors and prevent the release of gases.

iii. **Leachate Treatment:** If leachate is generated, it needs to be treated to remove contaminants before being released into the environment or into wastewater treatment systems. Treatment methods include physical, chemical, and biological processes.

iv. **Bioreactor Landfills:** Bioreactor landfills enhance waste degradation, which can lead to higher leachate production but shorter landfill lifespans. Proper management is required to handle the increased leachate generation.

v. **Waste-to-Energy:** Some waste-to-energy processes, like incineration, can reduce the volume of waste going to landfills, potentially reducing leachate generation.

vi. **Public Awareness and Education:** Promoting public awareness about proper waste disposal, recycling, and the potential hazards of landfill leachate can lead to more responsible waste management behaviors.

vii. **Innovative Technologies:** Ongoing research and development are exploring innovative technologies for leachate management, such as advanced treatment methods and enhanced landfill designs.

5. FUTURE DIRECTIONS:

Future research should aim to improve our understanding of leachate composition, the long-term health effects of exposure, and the effectiveness of different mitigation strategies. Additionally, public awareness and education are crucial for fostering support for better waste management practices.

6. CONCLUSION:

Landfill leachate presents significant health risks to nearby communities through various exposure pathways. Proper landfill management, effective regulation, and community engagement are essential to minimize these risks and protect public health. This paper emphasizes the need for continued research and collaboration to address the complex challenges posed by landfill leachate.

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